Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

BARRIERS TO ADOPTING METAVERSE TECHNOLOGY IN MANUFACTURING FIRMS

Ihab KA Hamdan[1], Wulamu Aziguli[1], Dezheng Zhang[1] and *Belal Al-Hakeem[2]

[1]University of Science and Technology Beijing, China
[2]Thamar University, Dhamar, Yemen

Abstract

Metaverse technology (MT) signifies a computer-generated sphere where operators can interconnect in a virtual setting. The adoption of MT has the possibility to transform business operation methods, business-to-customer interaction, and firm-worker collaboration approaches. On the other hand, some problems should be tackled and overcome to guarantee the success of adopting the MT. The research seeks to investigate MT adoption in manufacturing firms, emphasising estimating possible hindrances to present effective adoption plans. The data for this study was gathered from 311 participants in manufacturing companies in Palestine. This study uses machine learning tools, namely artificial neural network (ANN) modelling, combined with structural equation modelling (SEM) to assess the theoretical framework. The SEM findings showed that a company's technological inadequacies are the most critical obstacle to MT adoption in manufacturing firms. The ANN findings underlined the company's technological inadequacies as the most vital input, poor regulation and governance, incorporation barriers, low perceived usefulness among consumers, weak collaborative actions, low dedication from stakeholders, conservative company culture, and low transmission over the networks. As MT is prospective to offer companies competitive benefits, better efficiency, enhanced consumer involvement and stimulated innovation, it is imperative to deliberate and foster resolutions to adoption risks in the businesses. Firms can achieve successful adoption of the intriguing and rapidly everchanging technological environment by solving those risks/barriers. The research gives new understandings to MT inventors and managers for effective MT adoption in manufacturing firms and novel conceptual insights for practitioners intending to adopt this technology in their manufacturing firms.

Keywords: *Manufacturing, artificial neural network, virtual reality, augmented reality, technology adoption, metaverse.*

1. Introduction

In recent years, metaverse technology (MT) has become a well-liked environment where people can communicate with one another in a virtual setting (Yao et al., 2024). The MT can transform manufacturing businesses by enabling real-time tracking of products and services (Yao et al., 2024). This power could lead to more transparency, reduced expenses, and increased efficiency. Virtual markets could be established in the MT to facilitate trade between buyers and sellers. Thus, MT-based processes could be more cost and time-effective than conservative manufacturing strategies. Another advantage of MT in manufacturing firms is the capability to develop manufacturing frameworks and assess the latest technological innovations and strategies. This technology may help identify potential issues and improve manufacturing procedures before being used in the real world.

The potential for virtualization is one of the MT's most important effects on firms' operations (Queiroz et al., 2023). By creating virtual representations of actual items, firms can simulate distribution and production activities, identify challenges, and assess many settings to enhance firms' functionalities (Queiroz et al., 2023). Firm participants may have a platform for cooperation and communication through the MT. In a virtual environment, teams can collaborate, share data, and make decisions immediately, improving productivity and reducing delays (Queiroz et al., 2023). Another possible benefit of the MT is the ability to track products through every step of their existence. By creating a digital twin of a product, businesses can keep track of its location, condition, and performance. This procedure enables them to decide on maintenance, repairs, and replacements based on data (Queiroz et al., 2023).

The ability of MT to expand the touchable sphere through virtual and augmented reality

**Corresponding Author - E- mail: belalalhakeem@proton.me*

technological innovations might have an impact on many industrial segments, such as social media, healthcare, education, and marketing (Dwivedi et al., 2022). However, significant risks related to the MT's development must be considered. One of the key challenges is the absence of the technology and infrastructure required to reinforce a completely practical, cross-stage MT (Dwivedi et al., 2022). Establishing a fully functional MT still requires significant infrastructure and technological advancement, even if mesmeric cybernetic domains and computerized entertainment will offer awareness of MT's potential economic and social impacts (Dwivedi et al., 2022).

MT has some drawbacks in addition to advantages. Despite a thorough review of the corpus of literature on the topic, we could not find any studies or research articles that specifically experimentally examined the difficulties posed by MT in manufacturing firms. This study highlights the need for more research in this field and shows a large knowledge gap about MT's potential challenges and limitations. For several reasons, identifying the MT's barriers is important. First, this information may help guide the creation and introduction of MT by ensuring that any potential issues and restrictions are dealt with and reduced to encourage general acceptance and utilization. Second, being aware of the hindrances to the MT may help uncover issues that may necessitate additional research and invention to fix and advance the field. Thirdly, by identifying the impediments to MT, regulators and policymakers will be well-equipped to supervise, control, and deploy the technological innovations that makeup MT ethically and sensibly. Before deploying MT, the problems that prevent its adoption can be solved. Understanding the needs of everyone involved with or thought to benefit from the MT, despite their experience or resourcefulness, will also be helpful. As a result, this study aims to discover what hindrances exist for integrating MT into manufacturing firms in Palestinian manufacturing firms. Below are the study questions:

i. SQ1. What hindrances face the adoption of MT in Palestinian manufacturing firms?
ii. SQ2. What impact do the hindrances have on the adoption of MT in Palestinian manufacturing firms?

Most of the existing research on the use of MT in firms focused on the advantages and difficulties, and it has been hypothetical and investigative in character (Queiroz et al., 2023). The scarce MT applications in manufacturing-related research prompted this paper. This research employed an artificial neural network (ANN), which is together a nonlinear and a linear correlation, in addition to testing the proposed model through structural equation modelling (SEM), to ascertain the effectiveness of the predictors and predicted variables in the suggested theoretical framework (Khaw et al., 2022). To get beyond SEM's drawbacks, the subsequent examination step utilises the ANN method (Faasolo & Sumarliah, 2022a). Moreover, this study significantly contributes to the field of MT adoption by offering valuable insights and addressing challenges specific to the local context of manufacturing companies in Palestine. Incorporating a diverse range of participants from this region adds depth to the findings, making them particularly relevant for businesses operating within Palestine's unique socio-economic and technological landscape (Hamdan et al., 2022). The research identifies technological inadequacies as a primary obstacle and sheds light on additional barriers such as poor regulation, incorporation challenges, and cultural factors. These nuanced insights provide a comprehensive understanding of the hurdles that companies in Palestine may face when adopting MT.

Furthermore, the research contributes by leveraging advanced methodologies, combining artificial neural network (ANN) modelling with structural equation modelling (SEM). This innovative approach enhances the reliability and robustness of the findings, offering a sophisticated analysis of the factors influencing MT adoption. The machine learning tools employed in this study contribute methodologically to the field, showcasing the adaptability and effectiveness of such techniques in exploring complex relationships within the realm of technology adoption. This advances the theoretical framework and provides a blueprint for future research activities aiming to integrate machine learning methodologies in analysing technology adoption in diverse contexts.

The insights from the study on MT adoption in the Palestinian local context hold significant relevance for businesses worldwide. Identifying cultural factors as pivotal barriers underscores the need for a nuanced understanding of how cultural nuances impact technology adoption (Kholaif et al., 2023). This understanding extends beyond Palestinian businesses, offering a valuable lesson to companies globally on the importance of tailoring strategies to navigate cultural challenges. Recognizing conservative company culture hindering adoption serves as a universal guide for businesses, prompting them to develop strategies that align with specific cultural contexts to successfully integrate transformative technologies like MT.

Moreover, the study's exploration of regulatory and governance challenges in Palestine sheds light on a pervasive issue that transcends borders. The finding that poor regulation can impede MT adoption is transferable to countries where regulatory frameworks lag behind technological advancements. This insight serves as a global lesson, prompting policymakers and businesses worldwide to proactively address regulatory challenges, thereby ensuring a smoother and more successful adoption of MT.

2. Theoretical Background

2.1 Metaverse technology

Neal Stephenson initially employed the word "MT" to explain virtual-reality worlds where persons may interact with each other and use computer-generated items (Kim et al., 2023). Since then, the concept has expanded to include more immersive experiences and technological innovations. As the concept of the MT has gained more prominence, investors and technology companies have started to talk about it. One of the MT's innovations has been the rise of massively multiplayer online role-playing games (MMORPGs), including World of Warcraft and Second Life (Wiederhold, 2022). In these games, players can create avatars and interact with one another in a shared virtual environment. These users also create a mesmeric involvement that merges actual and virtual worlds by incorporating elements of social networks and electronic commercial platforms. Wiederhold (2022) argued that the concept of the MT is not entirely novel. It has long been employed in video games, publications, and movies. However, technical advancements, notably in augmented and virtual reality (AR/VR) and the growth of online games and social media, are to blame for the recent increase in interest in MT (Wiederhold, 2022).

The MT, which turns the current 2-D network into a completely mesmeric 3-D actuality, is considered the next phase in the evolution of the internet (Belk et al., 2022). Beyond the limitations of a normal screen and keyboard, users might interact with the content more organically and intuitively. One of the key aspects of the MT is its interconnectedness (Belk et al., 2022). Instead of different virtual worlds, the MT will be a connected system of places, interactions, and experiences. Users might easily move between virtual environments, engaging with other users and virtual objects (Belk et al., 2022).

The MT can potentially transform firms, leading to tremendous advancements and efficiencies in various domains. It does this through its interconnected virtual space that enables people to interrelate with virtual experiences and resources. Some possible outcomes are inventory management, virtual warehousing, cost reductions, storage management, and immediate stock visibility. The MT is a useful tool for teamwork, increasing accountability, and restructuring manufacturing processes. Applications for AR/VR powered by the MT can facilitate worker training and maintenance.

Nevertheless, many difficulties can exist in adopting MT. Two significant hindrances are interoperability, governance and regulation (Golf-Papez et al., 2022). In order to execute the MT, the computer-generated world and related programmes need to be linked to each other for interactions. Thus, close cooperation and coordination must exist among numerous enterprises and supply-chain partners. As soon as the MT becomes popular and influential, questions about how it should be governed will arise. Content moderation, security, and privacy issues should be resolved to make MT a safe and welcoming place for all users (Golf-Papez et al., 2022), especially in manufacturing firms (Ren et al., 2024).

2.2 TOE theory

The technological, organizational, and environmental (TOE) concept looks at the elements that affect how MT is adopted and used in organizations. According to this paradigm, the interaction of three important elements, including technology, organization, and environment, will determine if new technological innovations, like MT, are successfully adopted in SC management. The technological aspect is concerned with the characteristics and qualities of the newly developed MT, including its observability, compatibility with the current system, intricacy, and trialability. Organizational aspects include a firm's in-house structures, values, and procedures—including its degree of control, size, and organization—as well as the viewpoints and mindsets of its staff members about MT. In addition, the environmental aspect includes any external elements that impact a business, such as the competitive landscape, regulatory environment, and larger societal and commercial developments. By examining how these three components interact, organizations may better comprehend the promise and limitations associated with adopting new technology. With this knowledge, companies may create more effective plans to manage adjustments and maximise the benefits of using technological innovations.

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

2.3 The Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology

The Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) are prominent frameworks in information systems and technology adoption. TAM is preferred for its simplicity, providing a straightforward approach with limited constructs, primarily focusing on perceived ease of use and perceived usefulness (Aburbeian et al., 2022). This simplicity makes it highly practical for researchers and practitioners seeking an efficient model to assess users' attitudes and intentions toward technology adoption. Its extensive validation in diverse contexts and industries underscores TAM's effectiveness, establishing it as a well-established and reliable model (Al Moteri & Alojail, 2023). Moreover, TAM played a foundational role, laying the groundwork for subsequent theories and models that further explore the essential factors influencing technology adoption (Aburbeian et al., 2022).

On the other hand, UTAUT is recognized for its comprehensive nature, as it integrates multiple factors from various existing models, including TAM, Theory of Reasoned Action (TRA), and TAM2. By encompassing a broad range of determinants, UTAUT provides a more holistic understanding of technology acceptance (Tamilmani et al., 2021). Notably, UTAUT acknowledges the influence of cultural and social factors on technology adoption, incorporating constructs like social influence and facilitating conditions. This recognition enhances its applicability across diverse technologies and user groups, making it adaptable for studying the adoption of various technological innovations.

The choice between TAM and UTAUT depends on the specific research objectives, the technology under investigation, and the analytical depth required. TAM's simplicity makes it a suitable choice for straightforward assessments, while UTAUT's comprehensive nature is advantageous when exploring a broader spectrum of factors influencing technology acceptance (Tamilmani et al., 2021). Researchers often select these models based on their established track record, relevance to the study context, and the need for a nuanced understanding of user behaviour in technology adoption. TAM and UTAUT continue to play pivotal roles in shaping our insights into the intricacies of technology acceptance and use across diverse domains (Al Moteri & Alojail, 2023).

2.4 Hypotheses development

2.4.1 Technological inadequacies

Despite its potential as the enabler of the manufacturing industry’s resilience, the MT must be developed because it is only a conceptual framework (El Jaouhari et al., 2023; Ren et al., 2024). Some technical barriers may significantly impact firms' application of MT. One of the biggest challenges to adopting an MT for firms is the requirement for a sophisticated and cutting-edge technological infrastructure (Gupta et al., 2024). This need includes the networking and communication technological innovations essential for multiple stakeholders and the software and hardware facilities required to operate and build the MT (Gupta et al., 2024). Another challenge is the requirement for high-functionality processing and machine supplies. Real-time utilization of advanced visual processing tools and other technologies is necessary for the complex virtual world of the MT. Due to the high price of this equipment, large invested capitals are required (Chen et al., 2024). Furthermore, there are issues with the privacy and safety of crucial company documents in the MT in industrial manufacturing (Ren et al., 2024). Data security and privacy is a concern that needs to be addressed when adopting the MT for firms (Gupta et al., 2024), especially in manufacturing firms (Ren et al., 2024; Vafadarnikjoo et al., 2023). Other technical barriers in the adoption of MT in firms also include interoperability and high-speed communication and networking (Chen et al., 2024; Gupta et al., 2024) as well as scalability (Chen et al., 2024), trialability, smart wearable device, and internet penetration (Gupta et al., 2024). Therefore:

H1. Technological inadequacies significantly hinder the adoption of MT in manufacturing firms.

2.4.2 Poor authority and regulation

In order to ensure continuous interoperability and communication between the cybernetic applications and platforms, the MT—a virtual environment where people can interact with each other using digital sources—needs sufficient regulation (Chen et al., 2024). Operators cannot readily exchange data in various MT boards without these mechanisms. The lack of regulation makes creating and applying MT in firms more difficult. The activity of developing common formats, interfaces, and protocols is known as regulation, and it is intended to simplify communication and connectivity among numerous computer-generated networks. A lack of industrial standards could lead to developing private

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

solutions incompatible with different commercial entities (Chen et al., 2024).

The absence of uniformity limits the benefits of MT. The adoption of regulation is possible with competent governance. Due to a lack of governance, the distribution, ownership, and usage of intellectual and digital assets in the MT may be unclear and ambiguous. This might result in inconsistent technology application, which can cause mistakes and delays in business processes. The adoption of MT by business organizations may be hampered by their reluctance to commit substantial quantities of money in circumstances where the tenure and management of cybernetic systems are unclear. The success of the usage of MT in firms' management depends on governance and standards (Goldberg & Schär, 2023; Gupta et al., 2024). Without them, corporate companies would struggle to ensure the safety, interoperability, and authorized amenability necessary for widespread MT implementation. Regulatory and legal uncertainties are some challenges that manufacturing firms face in MT adoption (Vafadarnikjoo et al., 2023). As a result, it is assumed:

H2. Poor authority and regulation significantly hinder the adoption of MT in manufacturing firms.

2.4.3 Incorporation Barriers and the Failures to Adopt MT.

Incorporation and compatibility problems may make adopting the latest revolutionary technological innovations, such as MT, difficult or impossible in firms. Compatibility and interoperability issues are the main barriers to MT adoption in companies (Gupta et al. (2024), especially in manufacturing firms (Senna et al., 2022). If the latest creative technologies are incompatible with the existing system, adoption may be heavily resisted since problems with adoption may arise. Any unique technology, like MT, must cooperate with other virtual applications. Integration is among the most challenging risks that adopting MT into manufacturing brings. Integrating MT requires a high level of technical expertise. For businesses lacking technical knowledge, this incorporation offers significant entrance barriers. Another difficulty in incorporating MT into firms, according to Gupta et al. (2024) and Chen et al. (2024), is the need for interoperability among cybernetic platforms and existing systems. However, the use of MT in manufacturing firms may be slowed by integration issues (El Jaouhari et al., 2023), such as the difficulty of ensuring seamless connectivity across virtual systems. Thus:

H3. Incorporation barriers significantly hinder the adoption of MT in manufacturing firms.

2.4.4 Weak system transmission

Adopting MT in manufacturing systems will require a communication network with many users and interconnected devices (Ren et al., 2024). All stakeholders need seamless and immersive virtual-physical interactions; low-latency and real-time communication is vital for prompt accessibility (Ren et al., 2024). Thus, all manufacturing stakeholders must agree to and utilize MT for manufacturing systems. This process involves various parties, including consumers, retailers, distributors, and suppliers. Adopting MT in manufacturing firms requires infrastructure and stakeholder training (Gupta et al., 2024). If the potential advantages of technologies (such as enhanced efficiency, sustainability, and transparency) are being understood by stakeholders, it is possible that they will accept or use it (Maier & Weinberger, 2024). Conversely, when the company partners think it's too complicated, they might not embrace it, which would cause a poor network spread. A significant reason the adoption of MT for manufacturing firms has failed is inadequate network distribution. Therefore:

H4. Weak system transmission significantly hinders the adoption of MT in manufacturing firms.

2.4.5 Conservative organizational values

According to Arena et al. (2023), "organizational culture" refers to a group of shared views, values, norms, and behaviours that affect what means workers communicate inside and outside the firm. Organization's conservative values are distinguished by hierarchical structures, central decision-making authority, and a propensity for regularity and predictability. Corporate culture must be considered for firms to use MT (Gupta et al., 2024) efficiently. An open mind to innovation and approval of a lively culture of organizations are prerequisites for firms to adopt MT (Arena et al., 2023). Corporate culture that promotes the integration of VR/AR into workflows, upper management support, collaboration, trust, and transparency will enable the usage of MT (Gupta et al., 2024). Thus, the usage of MT for manufacturing firms may fail if these aspects are not considered. Hence, it can be assumed:

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

H5. Conservative organizational values significantly hinder the adoption of MT in manufacturing firms.

2.4.6 Low responsibility from stakeholders

Stakeholder commitment is one of the vital facilitators of MT adoption in the industry (Gupta et al., 2024). The dimension of stakeholders' responsibility is challenging due to the appraisal of the judgements, mindsets, and actions of different partners at many operative stages of manufacturing firms (Queiroz et al., 2023). The project was not completed on time because of stakeholders' low level of responsibility (Queiroz et al., 2023). It also results in opposition to organizational change. As a result, the stakeholders' work is also of inferior quality. Inadequate attention or investment in the capital required to ensure excellent adoption may lead to low responsibility from stakeholders (Queiroz et al., 2023; Dwivedi et al., 2022). It might also happen due to people's lack of curiosity and ignorance about the advantages of new technological innovations. If stakeholders are not committed to employing MT for manufacturing firms, they cannot support increasing the network's efficacy. Low responsibility, postponements, and high costs would come from this circumstance. Consequently, we suggest:

H6. Low responsibility from stakeholders significantly hinders the adoption of MT in manufacturing firms.

2.4.7 Lack of perceived usefulness from users

Customers are the most significant stakeholders for firms. If customers cannot instantly comprehend the benefits of a technology, they are less likely to adopt it. Due to this deficit, the demand for the technology declines and there is less enthusiasm for it (Adams, 2022). A firm's willingness to invest in technologies in default of receiving sufficient consumer support hinders the development and use of MT (Adams, 2022). Negative customer feedback or the notion that MT is useless could prevent prospective consumers from adopting it. Thus, when deploying MT for manufacturing, firms must consider consumers' wants and perceptions to ensure their success. Hence:

H7. The lack of perceived usefulness from users significantly hinders the adoption of MT in manufacturing firms. A model (Figure 1) was created based on the previous conversation.

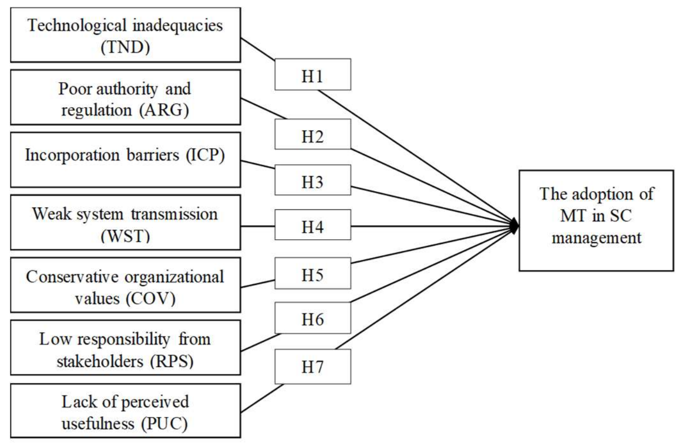

Figure 1 Theoretical model

3. Methodology

3.1 Measurement items

In order to manage a firm's SC management, this study sought to investigate the structural implications of adoption hurdles for MT. According to earlier research (Queiroz et al., 2023; Mozumder et al., 2022; Dwivedi et al., 2022), this research recognized eight major variables as significant for the hurdles to MT application for controlling a company's SC management. These eight constructs were lack of perceived usefulness from consumers (PUC), low responsibility from stakeholders (RPS), technical barriers (TND), Poor authority and regulation (ARG), incorporation challenges (ICP), weak system transmission (WST), conservative organizational values (COV), and the adoption of MT in SC management (AMT). TND has 4 items; ARG has 4 items; ICP, 4 items; WST, 5 items; COV, 3 items; RPS, 3 items; PUC, 3 items; AMT, 5 items (as seen in Appendix Table A1). The elements were adjusted from current academic work to retain construct and content authority.

Three elements comprised the entire survey questionnaire: the measurement items for the variables, the company's background, and the respondents' demographic profile. This paper used a 5-point Likert scale, with 55 representing "strongly agree," and 1 representing "strongly disagree" to obtain the respondents' perceptions of the variables' measurement items. To guarantee face and content validity, the inquiry form was pre-assessed by five academic researchers and five professionals in information technology systems and SC. After reviewing the instrument's face and content validity, minor changes were made to the arrangement and language of the constructions' elements. 50 participants—two from each of the 25 IT consulting

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

firms—were used in a pilot study. For each construct, the outcomes produced a respectable point of Cronbach's alpha (>.70). After the instrument's pilot test period of two weeks, the final survey was given out.

3.2 Sample and procedure

For our study, 215 manufacturing firms were chosen from random Palestinian area, which consists of the West Bank and Gaza Strip. As a result, 430 respondents working in these 215 manufacturing firms were invited to participate in the online poll. Of the 430 people who took the survey, 311 finished it with valid responses for further examinations. Table 1 shows more information about the demographic characteristics of the respondents who finished the survey. Over six months, the survey was carried out. Table 1 presents the findings of the descriptive analysis.

Table 1 Respondents' demography

Characteristics	Description	Frequency (N=311)	Proportion
Age	20-29	15	4.82%
	30-39	130	41.80%
	40-49	121	38.91%
	50-59	27	8.68%
	60 and above	18	5.79%
Education	Undergraduate	53	17.04%
	Graduate	161	51.77%
	Postgraduate	97	31.19%
Role	Owner	15	4.82%
	CEO	36	11.58%
	Senior Manager	175	56.27%
	Manager	67	21.54%
	Staff	18	5.79%
Type of firms	Food manufacturing	82	26.37%
	Pharmaceutical manufacturing	32	10.29%
	Furniture manufacturing	51	16.40%
	Apparel manufacturing	101	32.48%
	Glassware manufacturing	45	14.47%
Firm's size (worker number)	20 and below	5	1.61%
	21-50	94	3.23%
	51-100	161	51.77%
	Above 100	51	16.40%
Firm's age	Below 5 years	87	27.97%
	5-10 years	217	69.77%
	Above 10 years	7	2.25%

3.3 Common method bias

The problem of common method bias (CMB) has received a lot more attention recently in empirical research in management studies (Fassolo & Sumarliah, 2022b; Usmanova et al., 2021; Hamdan et al., 2022a; Sumarliah & Al-Hakeem, 2023). While the organized mistake variation is incorporated into the sizes of the structures, CMB is present. In order to ascertain if CMB was a problem with the gathered data series, the current study used both procedural and statistical methodologies (MacKenzie & Podsakoff, 2012). During data collection, the researchers informed the respondents about this study objective that their anonymity would be protected and that they could reply to the assertions of the associated variable sizes according to their opinion since there were no wrong or right responses. To ascertain whether CMB existed in the data set, Harman's (1976) common factor analysis was also used to study the data. The results of this study showed that only 29.28% of the variance could be accounted for by a single factor. Since the findings were below 50%, CMB had no effect on the data set that had been gathered.

3.4 Factor examination

Before starting the official data examinations, this study methodically assessed the fundamental postulations in regression assessment, such as multicollinearity, the nonexistence of homoscedasticity and auto-correlation, multivariate normality, and linearity. The study employs Ramsey's RESET assessment to check linearity. The assessment displayed no statistical significance regarding cubed and squared relations of independent variables if inserted into the expanded regression framework, confirming the linearity postulation for the predicted variable. Contrarywise, for the predictor, cubed and squared relations showed statistical significance, requiring their addition in the later regression examination. Other analytic assessments were performed to confirm other regression postulations. The entire Variance Inflation Factor (VIF) numeral

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

representations were less than 1.6, denoting that multicollinearity doesn’t exist. The Durbin-Watson statistical assessment (p-value=0.447; β=2.264) demonstrated no significant auto-correlation, and the Goldfield-Quandt assessment confirmed the nonexistence of heteroskedasticity (p-value=0.01, β=0.772). The Quantile-Quantile charts, directly next to an upright passage, signified an estimated normal dispersal of the residues. Besides, unidimensionality and local independence were examined in the Rasch test and showed support because MADaQ3 was below 0.20, and the initial factor’s eigenvalue within the principal component analysis of the normalized residues was below 2.00 for the entire counting measures.

4. Data assessment

We used covariance-centred SEM to assess the presented premises after doing validity and reliability examinations using CFA and EFA. As a result, we used a multi-stage information examination method (ANN-SEM) to forecast the causes of the hindrances to SC management's adoption of MT. Based on a variety of justifications, we operationalized these two statistical techniques. First, by concentrating solely on the numerical type, the SEM result only identified linear associations, which can have affected executive decision-creating progressions (Leong et al., 2020). In contrast to SEM, the ANN approach may identify linear and nonlinear relationships for prediction, which may help with the complexity of managerial decision-making processes (Faasolo & Sumarliah, 2022a). Finally, this work used a dual-phase method to examine information that incorporated both ANN and SEM to solve the drawbacks of ANN and SEM and supplement the outcomes of SEM. SEM was used to assess the proposed hypotheses, and the ANN model was used to investigate the significant predictors.

4.1 Validity and reliability

We used EFA to evaluate the measurement model's validity and dependability. We used rotating principal components and varimax techniques in this process. The main goal of the EFA examination was to evaluate the hypothesized aspects' agreement with the investigation information. The findings revealed the existence of nine criteria that lined up with those mentioned in the research model. Each construct produced a Cronbach's alpha that fell within a reasonable range, ensuring the accuracy of the accompanying constructs. The research constructs' convergent validity was also supported by the fact that each construct's individual eigenvalue exceeded 1.00 (Hair et al., 1998). Table 2 displays the findings of the EFA study.

Table 2 Variables’ psychometric features

Variable’s scales	λ	α	AVE	CR
Technical inadequacies (TND)		.859	.570	.849
TND1	.836			
TND2	.763			
TND3	.751			
TND4	.760			
Poor authority and regulation (ARG)		.916	.603	.867
ARG1	.807			
ARG2	.766			
ARG3	.842			
ARG4	.807			
Incorporation barriers (ICP)		.877	.635	.883
ICP1	.820			
ICP2	.808			
ICP3	.860			
ICP4	.793			
Weak system transmission (WST)		.865	.608	.895
WST1	.808			
WST2	.790			
WST3	.781			
WST4	.755			
WST5	.751			
Conservative organizational values (COV)		.811	.607	.829
COV1	.742			
COV2	.816			
COV3	.852			
Low responsibility from stakeholders (RPS)	.000	.816	.582	.812
RPS1	.781			

RPS2	.832			
RPS3	.740			
Lack of perceived usefulness (PUC)		.921	.613	.834
PUC1	.813			
PUC2	.805			
PUC3	.801			
The adoption of MT (AMT)		.905	.627	.903
AMT1	.854			
AMT2	.810			
AMT3	.781			
AMT4	.779			
AMT5	.761			

CFA was used in this stage of information examination to analyze the calculation type and ascertain the reliability of the variables. According to the outcomes of the CFA analysis, all constructs had standardized loadings that were over .50 and, therefore, significant (see Table 2). Hence, this finding demonstrates that convergent validity was met by each item under each construct (Kline, 1998). The measuring items appeared legitimate based on the CR (composite reliability) values of the entire variables, which were over the .7 threshold. Additionally, the matching AVE values for each concept, as displayed in Table 2, all exceed 1, demonstrating adequate concurrent authority. Since the square roots of all the variables' AVEs were bigger than their correlation amounts, as illustrated in Table 3, the calculation type analysis likewise validated discriminant authority for all the dormant variables. The CFA examination's findings showed that the entire goodness-of-fit statistics were valid. Table 4(A) shows that the dimension framework fits the data satisfactorily.

Table 3 Discriminate validity

Variables	Relationships							
	TND	ARG	ICP	WST	COV	RPS	PUC	AMT
TND	.760							
ARG	.446	.782						
ICP	.476	.385	.802					
WST	.404	.324	.403	.785				
COV	.413	.505	.412	.435	.785			
RPS	.434	.435	.424	.426	.309	.768		
PUC	.424	.445	.480	.411	.415	.425	.789	
AMT	.445	.424	.414	.424	.419	.442	.444	.797

Notes: TND=Technical inadequacies; ARG=Poor authority and regulation; ICP=Incorporation barriers; WST=Weak system transmission; COV=Conservative organizational values, RPS=low responsibility from stakeholders; PUC=lack of perceived usefulness from consumers; AMT=the adoption of MT in SC.

Table 4 Fitness of measurement framework (A) and structural framework (B)

Fitness measure	Outcomes		Advised threshold
	A	B	
RMSEA (root mean square error of approximation)	.039	.027	≤.08
NFI (normed fit index)	.968	.943	≥.90
CFI (comparative fit index)	.988	.973	≥.90
AGFI (adjusted goodness-of-fit index)	.915	.924	≥.90
GFI (goodness-of-fit index)	.964	.952	≥.90
X^2 test statistic/df	1.228	1.998	≤3.00

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

4.2 Structural framework

AMOS 2.0 was used to test the structural model's overall validity. The developed conceptual model shows Eight characteristics that were defined as impediments to the use of MT for SC management (Figure 1). The study of the structural model's results revealed that all fit indices, including NFI, AGFI, CFI, and GFI, had values over .90, but RMSEA was less than .08. Also acceptable was the normed chi-squared index (X2/df=1.228). The structural model, therefore, made sense. Table 4(B) presents the outcomes of the goodness-of-fit indexes.

4.3 SEM assessment

The SEM procedure was used to examine the proposed hypotheses. The analysis's findings supported the hypothesis (H1 to H8) by showing a positive and significant correlation between technological constraints, poor authority and regulation, incorporation challenges, weak system transmission, conservative organizational culture, low responsibility from stakeholders, and low customer perceptions of value.

The findings showed a significant positive correlation between a company's technological constraints and its failures to adopt MT for SC management (β=.598, p <1 t-value =4.883), followed by a poor authority and regulation (β =.407, p <1%, t-value =3.759), incorporation challenges (β=.382, p <1%; t-value =3.099, diffusion through the network (β=.314, p <1%, t-value =3.086), conservative organizational culture (β=.277, p <1%, t-value =3.007), low responsibility from stakeholders (β=.221, p <1%, t-value=2.398, and inadequate customer's perceived usefulness (β=.155, p <0%; t-value=2.743). Figure 2 shows the correlations between these variables and the corresponding β (effect coefficient) of the entire hypotheses. These findings likewise showed that the underlying framework accounts for 55.23 per cent of the variation in the hindrances to the adoption of MT, showing a 46.31 per cent impact extent and supporting a big impact.

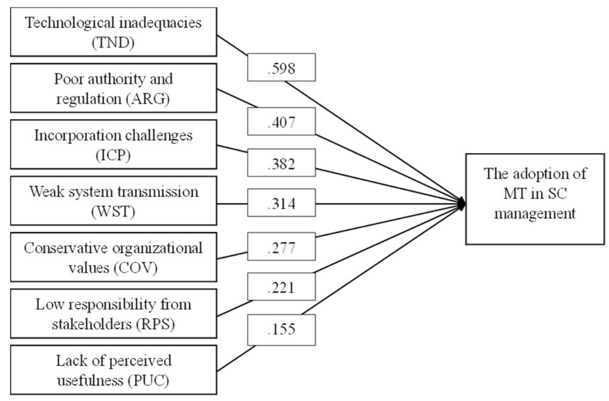

Figure 2 Findings of SEM assessment

4.4 ANN assessment

Because SEM can only explain linear correlations between variables, it will likely oversimplify the managerial decision's complexities while attempting to comprehend the hindrances to the deployment of MT for SC MANAGEMENT. Because discoveries from ANN may uncover both non-linear and linear correlations, which have higher robustness and will offer greater estimation accuracies, this research used ANN-SEM techniques for statistical examination to solve the limits of SEM findings (Faasolo and Sumarliah, 2022a). In order to investigate non-linear correlations between the variables in the prediction model, deep ANN modelling was used in the study. Barriers to the adoption of MT for SC MANAGEMENT were categorized as high (>10), medium (7–10), and low (<7). The statistics were processed by a neural network multi-tier perceptron method with 2 concealed tiers using SPSS version 22. 8 independent variables were utilized to forecast the dependent variable in a sigmoid activation process that was operationalized along with cross-validation. This process was selected for the purpose of concealed output and neurons. The root-mean-square error (RMSE) worth for the testing and training statistics was entirely within suitable bounds, according to the ANN analysis outcomes. The outcomes of the ANN examination closely matched those of the SEM study. For a firm's SCN, the deep ANN model predicted adoption hurdles for MT with an average accuracy of 6.06% (testing) and 69.50% (training), as seen in Table 5.

Journal of Manufacturing Engineering, ISSN: 0973-6867, December 2024, Vol. 19, Issue. 4, pp 146-162
DOI: https://doi.org/10.37255/jme.v19i4pp146-162

Table 5 Categorization accuracies and RMSEs

Networks	Total testing SE (AMT)	Total training SE (AMT)
ANN-01	.709	.801
ANN-02	.719	.638
ANN-03	.661	.719
ANN-04	.617	.727
ANN-05	.607	.714
ANN-06	.712	.708
ANN-07	.616	.727
ANN-08	.781	.709
ANN-09	.729	.689
ANN-10	.754	.628
Std Dev	.061345	.048672
Mean	.615	.706

Note: SE= square error; AMT=the adoption of metaverse technology in manufacturing processes. **Source**: Authors' work (SPSS)

In order to determine the relative effect of the predictor factors on the predicted factor, we conducted a sensitivity analysis. The analysis's findings highlighted the significance of several factors, including technological inadequacies (2.29%), poor authority and regulation (17.52%), incorporation difficulties (15.67%), weak system transmission (12.29%), conservative organizational values (1.89%), a low responsibility from stakeholders (9.39%), and lack of perceived usefulness from consumers (6.91%).

The analysis's findings highlight the critical elements that are essential to the efficient application of MT in SC management. Understanding these aspects is crucial for companies looking to implement and use this disruptive innovation efficiently. "Technical barriers (Importance: 2.29%)" is the first factor. This aspect suggests that certain technical barriers might make incorporating MT into current SC systems difficult without any noticeable disruption. To fully utilize the MT, these barriers must be removed so enterprises can network and explore new opportunities. Both the sum of square errors during training and testing or AMT, optimize their processes. "Poor authority and regulation (Importance: 17.52%)" is the second element. The lack of distinct governance and regulation frameworks makes developing an industry-wide, standardized strategy for employing MT difficult.

"Incorporation Challenges (Importance: 15.67%)" is the third factor. It is a difficult undertaking to integrate MT with current SC procedures. How efficiently enterprises can use the MT to improve communication, transparency, and efficiency through the SC will depend on how well they handle incorporation difficulties. "Weak system transmission (Importance: 12.29%)" is the fourth factor. Effective network adoption of MT necessitates strategic planning and focused initiatives. Maximizing the advantages of the MT requires overcoming change-related resistance and securing widespread adoption among pertinent parties. The sixth element is "Conservative Organizational Culture (Importance: 1.89%)". Technology adoption and deployment are significantly affected by organizational culture. A culture that is innovative, flexible, and open to new technologies will create the ideal conditions for successfully integrating MT solutions into manufacturing procedures.

"Low responsibility from stakeholders (Importance: 9.39%)" is the sixth factor. Any transformational technology adoption must first get the support of all relevant parties, including senior management, staff, and partners. A smooth and efficient MT incorporation will be more likely if alignment and buy-in are ensured. "Lack of perceived usefulness from consumers (Importance: 6.91%)" is the seventh factor. The adoption of MT into SC processes can be affected by how customers view the value it offers. Customers' acceptance and engagement will increase if the benefits of the MT are well explained to them and displayed.

This investigation highlights the fact that opportunities and constraints related to integrating MT in SC management are numerous. Organizations should position themselves for a successful transition by deliberately and proactively tackling these issues to use MT's potential to spur competitiveness, innovation, and efficiency in the sector. Executing the complete advantages of MT in a growing and lively environment will require adopting a holistic approach that considers stakeholder engagement, collaboration, value, and technology.

5. Discussions

5.1 Theoretical implications

The understanding of the challenges facing the deployment of MT in manufacturing firms has substantially improved as a result of this study. Our research has focused on the difficulties in applying digitalization and MT. For MT, sophisticated computer hardware and augmented or virtual software are required. The current study claims that a dearth of contemporary technology hinders the deployment of MT in manufacturing firms.

We discovered that the sector's current digital infrastructure is incompatible with MT. This study has found that technological constraints account for a substantial part of the difficulty in deploying MT for manufacturing firms. H1 is therefore supported. Dwivedi et al. (2022) provided an explanation of the relevance of the MT, a novel level of connectivity between the virtual and actual worlds that generate novel opportunities and possibilities for enterprise strategies. They recognized several challenges relating to MT, such as those pertaining to law, morality, ethics, and safety. The discoveries also discuss how a deficiency of authority causes stakeholders to be reluctant to embrace MT for manufacturing firms. According to this study, a lack of regulation and control results in morality, privacy, and security issues. Therefore, it supports H2.

Queiroz et al. (2023) claim that it is feasible to use MT in firms. These authors discuss the costs of deploying MT and the dearth of required skills. We may conclude from our analysis that expertise and human elements are key and that combining MT with other programs is imperative. The main barriers to incorporation are interoperability, complexity, and technological problems. Incorporation problems have a significant impact on the failures of MT in manufacturing firms. H3 is, therefore, supported.

A practical chain game is a clever technique to quicken the pace of digitization in firms (Salvini et al., 2022). They continue by saying that four hindrances must be removed: a lack of exigency, a dearth of a customer-centred approach, a dearth of comprehension of virtualise, and a dearth of collaboration. However, a weak diffusion network was a significant obstacle that these writers failed to mention. Poor communication could have a negative impact on manufacturing management efficiency and productivity since the information is unbalanced. According to the study described here, poor diffusion networks severely hinder manufacturing firms' adoption of MT. H4 is, therefore, supported.

The cost and technological acceptance are the biggest barriers to incorporating MT in firms (Queiroz et al., 2023). These authors did not discuss the conservative organization’s value, which is a barrier to adopting MT. According to the current study's findings, traditional organizational cultures are hostile to innovation and change, preventing MT adoption. Adopting MT in manufacturing firms is negatively impacted by a traditional organizational culture, which restricts a company's ability to benefit from the technology's advantages. A conservative company culture makes it more challenging for manufacturing firms to deploy MT successfully. H5 is therefore supported.

Queiroz et al. (2023) found that stakeholder concerns about the benefits of MT were another finding and that the application of MT in firms depends on effectiveness, inventiveness, and information exchange. This study confirmed that low responsibility from stakeholders is a major obstacle to the efficient deployment of MT. Due to stakeholders' low level of responsibility, businesses cannot participate in the MT adoption process. H6 is, therefore, supported.

In our study, the importance of customer perception in integrating MT has been further examined. This study has found that if customers do not see any advantages to using MT, they will not use it. Our results show that poor customer-perceived usefulness directly contributes to the failures of manufacturing firm initiatives utilizing MT. H7 is, therefore, supported.

5.2 Practical implications

One of the main hindrances to integrating MT in manufacturing firms has been found in this study as being technological limits. The major implication is that manufacturing firms should know their technology readiness. Leaders of manufacturing firms will initially undertake a technological audit to find any slits in the technological architecture of their company before addressing technological restrictions. The next step is determining which MTs are appropriate given the organisation's requirements. This strategy can assist in lowering the cost of IT infrastructure for businesses. Managers should take important actions to ensure the proper adoption of MT, including creating a thorough adoption plan and monitoring technology usage.

Lack of uniformity and governance is the second obstacle that has been identified. Leaders of manufacturing firms will adopt authority and regulation procedures and work with business associates to create consensus standards to overcome this problem. Managers must work with industry partners to develop best practices and common standards for utilizing MT in manufacturing firms. All stakeholders can more easily and consistently use the technology with the help of collaboration.

Organizations consistently face difficulties integrating new technology, notably MT, with their current systems. Organizations can work with stakeholders, pilot-test the incorporation of MT in a small-scale initiative, and recognize the constraints of their current IT infrastructure to get around this problem. Employee technical training can aid in the proper operation of the technological infrastructure.

When a new technology is launched, there is an issue with the network spread, and the MT is no different.

Businesses can take several steps to address the manufacturing firms ' low adoption of MT and their poor diffusion. To identify the factors that affect the acceptability of MT, such as the preferences and requirements of the participants, they should first perform market research. The second step is for managers to outline the benefits of integrating MT into manufacturing firms, such as improved efficiency, transparency, and traceability. Managers should form an alliance with technology specialists and various stakeholders to boost the adoption rate of MT in manufacturing firms.

Furthermore, the paper has shown that a conservative organization's values, which contain shared behaviours, customs, norms, and ideals that impact how employees interact with each other and shareholders external to the business, may make it difficult to use MT for manufacturing firms effectively. Companies can take several actions to get around this obstacle. They can first develop an open and innovative culture. Second, they can offer suitable instruction and assistance.

Stakeholder commitment is another crucial component for the successful use of MT in manufacturing firms. Since it necessitates analysis of different shareholders' attitudes, beliefs, and behaviours at numerous organization stages, it is difficult to quantify (Queiroz et al., 2023). To ensure successful adoption, businesses must get through the potential obstacle of low responsibility from stakeholders. To do this, companies must involve key parties initially in the progression and ensure that the entire parties are in accord with the benefits and goals of the technologies. Companies must also address stakeholders' objections or concerns, demonstrate the technology's probable advantages to them, reward those stakeholders and offer incentives that dynamically espouse its adoption.

The paper has also demonstrated low consumer perceived usefulness as a substantial element because consumer gratification and perceived usefulness are essential for its use in firms (Dwivedi et al., 2022). Businesses can take numerous steps to increase customer uptake and ensure a successful rollout. Businesses should conduct market research to understand customer wants and modify technology. Businesses should also explain to customers the benefits of utilizing MT in manufacturing firms, give them training and assistance to feel confident using the new technology, and reward and motivate users and supporters. By enhancing customer satisfaction and value perception, businesses can attract more companies to adopt MT for manufacturing firms.

6. Conclusion, limitations, and future studies

This research contributes significant insights into adopting MT within manufacturing companies in Palestine. The study reveals that the primary impediment to MT adoption is a company's technological inadequacies, emphasizing the critical role of addressing these deficiencies for successful integration. The application of advanced methodologies, such as ANN and SEM, enriches the findings, providing a nuanced understanding of the various challenges businesses face in adopting this transformative technology.

The practical implications derived from this research underline that companies must proactively tackle adoption risks to capitalize on the potential competitive advantages, increased efficiency, consumer engagement, and innovation offered by MT. The identified barriers, ranging from regulatory issues to cultural factors, underscore the complexity of the adoption landscape and highlight the need for tailored and strategic solutions. By fostering resolutions to these challenges, firms can navigate the dynamic and ever-changing technological environment, positioning themselves for successful MT adoption.

The originality and value of this research lie in its provision of new understandings for MT inventors, managers, and practitioners seeking effective adoption strategies. The novel conceptual insights contribute to the growing body of knowledge on MT adoption, offering a framework for navigating the intricate challenges companies face in their quest to integrate MT within their firms. As businesses contemplate the transformative potential of the metaverse, this study serves as a guide for informed decision-making, urging stakeholders to address barriers and cultivate an environment conducive to the successful adoption of MT within the manufacturing sector and similar industries.

MT has the potential to change SC management. Businesses must take into account a variety of adoption challenges, though. The first phase in this study's response to SQ1 was identifying the impediments. This study also looked at how these hindrances affect the usage of MT in SC management to address SQ2. Standards and protocols must be developed to enable system interoperability and remove technological hindrances. The adoption of MT can also be aided by invested capital in fast internet and powerful computers. To overcome organizational hindrances, resource management and strong leadership are required. Additionally, overcoming cultural hindrances necessitates the adoption of explicit regulations and procedures for information security and privacy, building stakeholder belief, and constructing a comprehensive atmosphere that fosters innovation and cooperation.

The fact that data were gathered from just one academic database (Scopus) is one of this study's shortcomings. We also conducted a survey of companies in Palestine that develop SC solutions and IT consulting services. The findings must be interpreted with these limitations in mind. Future studies could look at SC management adoption of the MT from an RBV or DCV standpoint.

Additionally, researchers and companies looking to understand the elements impacting the effective application of MT in business might benefit greatly from social media data. We can learn a lot about user views, needs, hindrances, and effective adoption methods by utilizing social media analytics. This information can help decision-makers and increase the success of projects that adopt the MT.

References

1. *Aburbeian, A. H. M., Owda, A. Y., and Owda, M., "A Technology Acceptance Model Survey of the Metaverse Prospects," AI (Switzerland), vol. 3, no. 2, pp. 285–302, 2022, doi: 10.3390/ai3020018.*

2. *D. Adams, "Virtual retail in the metaverse: customer behaviour analytics, extended reality technologies, and immersive visualization systems," Linguistic and Philosophical Investigations, vol. 21, pp. 73–88, 2022.*

3. *M. Al Moteri and M. Alojail, "Factors influencing the Supply Chain Management in e-Health using UTAUT model," Electronic Research Archive, vol. 31, no. 5, pp. 2855–2877, 2023.*

4. *M. Arena, S. Hines, and J. Golden III, "The three Cs for cultivating organizational culture in a hybrid world," Organizational Dynamics, vol. 52, no. 1, 2023, doi: 10.1016/j.orgdyn.2023.100958.*

5. *A. Barsoum, "Information and Communication Technology (ICT)," Country Commercial Guides, 2022. [Online]. Available: https://www.trade.gov/country-commercial-guides/west-bank-and-gaza-information-and-communication-technology-ict.*

6. *R. Belk, M. Humayun, and M. Brouard, "Money, possessions, and ownership in the metaverse: NFTs, cryptocurrencies, Web3 and wild markets," Journal of Business Research, vol. 153, pp. 198–205, 2022.*

7. *Z. S. Chen, J. Y. Chen, Y. H. Chen, and W. Pedrycz, "Construction metaverse: Application framework and adoption barriers," Automation in Construction, vol. 163, p. 105422, 2024.*

8. *Y. K. Dwivedi, L. Hughes, A. M. Baabdullah, S. Ribeiro-Navarrete, M. Giannakis, M. M. Al-Debei, and S. F. Wamba, "Metaverse beyond the hype: multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice, and policy," International Journal of Information Management, vol. 66, pp. 1–55, 2022.*

9. *A. El Jaouhari, J. Arif, A. Samadhiya, A. Kumar, V. Jain, and R. Agrawal, "Are metaverse applications in quality 4.0 enablers of manufacturing resiliency? An exploratory review under disruption impressions and future research," The TQM Journal, vol. ahead-of-print, no. ahead-of-print, 2023, doi: 10.1108/TQM-06-2023-0181.*

10. *M. Faasolo and E. Sumarliah, "Sustainability-oriented technology adoption in Tonga: the impact of Government's incentives and internal factors," International Journal of Emerging Markets, vol. ahead-of-print, no. ahead-of-print, 2022, doi: 10.1108/IJOEM-09-2021-1424.*

11. *M. B. Faasolo and E. Sumarliah, "An artificial neural network examination of the intention to implement blockchain in the supply chains of SMEs in Tonga," Information Resources Management Journal (IRMJ), vol. 35, no. 1, pp. 1–27, 2022.*

12. *M. Goldberg and F. Schär, "Metaverse governance: An empirical analysis of voting within Decentralized Autonomous Organizations," Journal of Business Research, vol. 160, p. 113764, 2023, doi: 10.1016/j.jbusres.2023.113764.*

13. *M. Golf-Papez, J. Heller, T. Hilken, M. Chylinski, K. de Ruyter, D. I. Keeling, and D. Mahr, "Embracing falsity through the metaverse: the case of synthetic customer experiences," Business Horizons, vol. 65, no. 6, pp. 739–749, 2022.*

14. *R. Gupta, B. Rathore, B. Biswas, M. Jaiswal, and R. K. Singh, "Are we ready for metaverse adoption in the service industry? Theoretically exploring the barriers to successful adoption," Journal of Retailing and Consumer Services, vol. 79, p. 103882, 2024.*

15. *J. F. Hair, R. E. Anderson, R. L. Tatham, and W. C. Black, Multivariate Data Analysis. Englewood Cliffs, NJ: Prentice-Hall, 1998.*

16. *I. K. A. Hamdan, W. Aziguli, D. Zhang, E. Sumarliah, and F. Fauziyah, "A machine learning method to predict the technology adoption of blockchain in Palestinian firms," International Journal of Emerging Markets, vol. 17, no. 4, pp. 1008–1029, 2022, doi: 10.1108/IJOEM-05-2021-0769.*

17. *H. H. Harman, Modern Factor Analysis. Chicago, IL: University of Chicago Press, 1976.*

18. *K. W. Khaw, A. Alnoor, H. Al-Abrrow, X. Chew, A. M. Sadaa, S. Abbas, and Z. Z. Khattak, "Modelling and evaluating trust in mobile commerce: a hybrid three-phase Fuzzy Delphi, structural equation modeling, and neural network approach," International Journal of Human–Computer Interaction, vol. 38, no. 16, pp. 1529–1545, 2022.*

19. *M. M. N. H. K. Kholaif, B. Sarwar, M. Xiao, M. Poliak, and G. Giovando, "Post-pandemic opportunities for F&B green supply chains and supply chain viability: the moderate effect of blockchains and big data analytics," European Journal of Innovation Management, 2023, doi: 10.1108/EJIM-10-2022-0581.*

20. D. Y. Kim, H. K. Lee, and K. Chung, "Avatar-mediated experience in the metaverse: The impact of avatar realism on user-avatar relationship," Journal of Retailing and Consumer Services, vol. 73, p. 103382, 2023.

21. R.B. Kline, Structural Equation Modeling, Guilford, New York, 1998.

22. L.Y. Leong, T.S. Hew, K.B. Ooi, and A.Y.L. Chong, "Predicting the antecedents of trust in social commerce–A hybrid structural equation modeling with neural network approach," J. Business Research, vol. 110, pp. 24-44, 2020.

23. S.B. MacKenzie and P.M. Podsakoff, "Common method bias in marketing: causes, mechanisms, and procedural remedies," J. Retailing, vol. 88, no. 4, pp. 542-555, 2012.

24. F. Maier and M. Weinberger, "Metaverse Meets Smart Cities—Applications, Benefits, and Challenges," Future Internet, vol. 16, no. 4, p. 126, 2024.

25. M.M. Queiroz, S. Fosso Wamba, S.C.F. Pereira, and C.J. Chiappetta Jabbour, "The metaverse as a breakthrough for operations and supply chain management: implications and call for action," Int. J. Operations & Prod. Management, vol. ahead-of-print, no. ahead-of-print, doi: 10.1108/IJOPM-01-2023-0006, 2023.

26. L. Ren, J. Dong, L. Zhang, Y. Laili, X. Wang, Y. Qi, B.H. Li, L. Wang, L.T. Yang, and M.J. Deen, "Industrial Metaverse for Smart Manufacturing: Model, Architecture, and Applications," IEEE Trans. Cybernetics, vol. 54, no. 5, pp. 2683-2695, 2024, doi: 10.1109/TCYB.2024.3372591.

27. G. Salvini, G.J. Hofstede, C.N. Verdouw, K. Rijswijk, and L. Klerkx, "Enhancing digital transformation towards virtual supply chains: a simulation game for Dutch floriculture," Prod. Planning Control, vol. 33, no. 13, pp. 1252-1269, 2022.

28. P.P. Senna, L.M.D. Ferreira, A.C. Barros, J.B. Roca, and V. Magalhães, "Prioritizing barriers for the adoption of Industry 4.0 technologies," Computers & Industrial Engineering, vol. 171, p. 108428, 2022.

29. E. Sumarliah and B. Al-hakeem, "The effects of digital innovations and sustainable supply chain management on business competitive performance post-COVID-19," Kybernetes, vol. 52, no. 7, pp. 2568-2596, 2023, doi: 10.1108/K-09-2022-1326.

30. K. Tamilmani, N.P. Rana, S.F. Wamba, and R. Dwivedi, "The extended Unified Theory of Acceptance and Use of Technology (UTAUT2): A systematic literature review and theory evaluation," Int. J. Inf. Management, vol. 57, p. 102269, Nov. 2020, doi: 10.1016/j.ijinfomgt.2020.102269.

31. K. Usmanova, D. Wang, E. Sumarliah, K. Mousa, and S.S. Maiga, "China's halal food industry: the link between knowledge management capacity, supply chain practices, and company performance," Interdiscip. J. Inf., Knowledge, and Management, vol. 16, p. 285, 2021.

32. A. Vafadarnikjoo, H. Badri Ahmadi, J.J. Liou, T. Botelho, and K. Chalvatzis, "Analyzing blockchain adoption barriers in manufacturing supply chains by the neutrosophic analytic hierarchy process," Annals of Operations Research, vol. 327, no. 1, pp. 129-156, 2023.

33. B.K. Wiederhold, "Ready (or Not) player one: initial musings on the metaverse," Cyberpsychology, Behavior, and Social Networking, vol. 25, no. 1, pp. 1-2, 2022.

34. X. Yao, N. Ma, J. Zhang, K. Wang, E. Yang, and M. Faccio, "Enhancing wisdom manufacturing as industrial metaverse for industry and society 5.0," J. Intelligent Manufacturing, vol. 35, no. 1, pp. 235-255, 2024.

.

Appendix

Table A1. Variables' scales

Variable	Scales	Underpinning literature
Technical barriers (TND)	TND1: The company faces challenges due to current information incorporation requirements. TND2: The company faces challenges due to the requirement for immediate processing of data. TND3: We lack the capacity to constantly track data from a variety of information, such as stocks, shipment timetables, and manufacturing timetables. TND4: We lack the capacity to continuously analyse information gathered from a variety of reports, such as stocks, shipping and manufacturing timetables.	Queiroz et al. (2023), Dwivedi et al. (2022)
Poor authority and regulation (ARG)	ARG1: There isn't an accepted norm for adopting MT. ARG2: There isn't a consensus on regulations for the administration of MT platforms. ARG3: It is difficult to transfer data across MT systems due to their various protocols, connections, and data forms. ARG4: Disparate systems produce silos of data that prevent coordination throughout the manufacturing activities.	
Incorporation barriers (ICP)	ICP1: Manufacturing infrastructures are frequently created independently ICP2: Managing the manufacturing structures with many standards and technologies is challenging. ICP3: Separate manufacturing processes are used ICP4: Because it necessitates crossing the divide between the real and virtual worlds, integrating the MT into current structures is difficult.	
Weak system transmission (WST)	WST1: MT is among the brand-new technologies that remains in its infancy. WST2: MT is not widely-known yet, therefore many individuals are reluctant to utilize it. WST3: Because of poor knowledge about the MT, a lot of people would be reluctant to accept it. WST4: Less individuals are using the MT and reaping its advantages. WST5: Weak networking dissemination might result from inadequate knowledge level.	
Conservative organizational values (COV)	COV1: Conservative organizational values might not be favourable to experimenting. COV2: Adopting the MT in manufacturing could involve undertaking risks within the Conservative organizational values. COV3: Collaborative and open communications could be absent in conventional businesses with inflexible structures and compartmentalized divisions.	
Low responsibility from stakeholders (RPS)	RPS1: There is insufficient cooperation from a range of all parties involved, especially consumers, ICT experts, and supply-chain partners. RPS2: The project's fulfilment is not a priority for all involved parties.	

	RPS3: Because MT is among the young and developing technologies, numerous parties are unsure of its advantages and possible financial gains.
Lack of perceived usefulness from consumers (PUC)	LVC1: Consumers are reluctant to make investments in the required ICT infrastructures. LVC2: Consumers are reluctant to use the MT in SC management. LVC3: The perception of consumers of MT as an innovative innovation with little application to their professional demands has decreased their enthusiasm in implementing MT.
The adoption of MT in SC (AMT)	AMT1: The project's objectives and purposes weren't clearly stated. AMT2: Unable to evaluate the the company's infrastructure's readiness for technology for supporting the MT. AMT3: If the organisation fails, a plan of action towards adopting MT can be created. AMT4: The required equipment for supporting the MT was not built. AMT5: The MT was not successfully tested and validated in an approved setting.